Proposal to the Bureau of Reclamation WaterSMART program: Applied Science Grants for the Southern Rockies Landscape Conservation Cooperative

Modeling low streamflows and assessing the ecological impacts of potential stream drying under climate change in the Upper Colorado River Basin

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Streamflows in late spring and summer have declined over the last century in the western US and mean annual streamflow is projected to decrease by six to 25% over the next 100 years. In arid and semi-arid regions of the western US, it is likely that some perennial streams will shift to intermittent flow regimes in response to climate-driven changes in timing and magnitude of precipitation, runoff, and evapotranspiration. We propose to address the following two research question: (1) how will small stream (1^{st}-3^{rd} order) low flow hydrology be impacted by predicted longer, drier summers in the Upper Colorado River Basin under climate change and (2) in turn, what will be the resulting impacts on riparian plant communities? To address these research questions we will undertake two major tasks: (1) model stream low flow metrics on ungaged streams in the UCRB and (2) sample riparian plant communities along a hydrologic gradient (perennial to intermittent) to develop statistical relationships between flow parameters and biotic responses that can eventually be used to help predict biotic changes under climate change-driven stream drying. Our proposed study directly addresses Southern Rockies LCC Project Task Areas A and B by projecting changes to surface water low flows and changes to riparian ecosystems, including distribution of invasive riparian plants, under future climate changes in the Southern Rockies LCC region. Task 1 will result in GIS data layers and maps for streams in the UCRB indicating how stream low flows may change under future climate scenarios that will be accessible on an interactive website. Task 2 will result in statistical models that relate flow parameters to riparian vegetation composition. Final products will include annual progress reports, a final report, a peer-reviewed manuscript, a final presentation, and an informational, interactive website accessible to land and water managers. The tasks included in this research will be carried out over 2 years, completed by September 2013.

Technical proposal: Technical project description

Climate change is expected to have both direct and indirect consequences on the structure and functioning of stream and riparian ecosystems in the western United States. The short-term effects of climate change on stream discharge in the western US are already apparent and are expected to intensify in the future. Some studies have revealed that peak stream flow timing has shifted to earlier in the spring over the last century and that runoff is likely to continue to occur earlier under most future change scenarios (Rood et al. 2008, Clow 2010). Streamflows in late spring and summer have also declined over the last century (Aguado et al. 1992, Dettinger and Cayan 1995, Westmacott and Burn 1997, Zhang et al. 2001, Burn and Hag Elnur 2002, Stewart et al. 2005, Rood et al. 2008). Further, mean annual streamflow is projected to decrease by six to 25% over the next 100 years (Christensen and Lettenmaier 2007, Barnett and Pierce 2009).

We propose to examine climate change impacts on stream low-flows and potential effects on riparian vegetation in the Upper Colorado River Basin (UCRB), located in the center of and comprising approximately half of the Southern Rockies LCC. The Colorado River is one of the most intensively managed river systems in the world and an extremely important water resource in the Southern Rockies LCC, providing water for millions of people, farms, livestock, power generation and natural ecosystems across seven states and two countries (Reisner 1986). The Bureau of Reclamation (Reclamation) plays a major role in managing Colorado River water and anticipating water supply and demand for this important region. In addition, the UCRB includes a region from the apex of the Rocky Mountains to the high deserts of the southwestern US, which is likely to sustain significant impacts due to climate change (Christensen and Lettenmaier 2007, Clow 2010).

Climate change effects on small streams, associated ecosystems and water users in the UCRB will be particularly important because small streams comprise most of the stream length in a given drainage and represent a significant portion of river-dependent ecosystems (Leopold et al. 1964). As in most drainages, 1^{st} - 3^{rd} order streams comprise 90% of stream length in the UCRB (NHD*Plus* 2010). Many small scale water development and management activities occur on small streams via diversions for agriculture and impoundments. Also, livestock operations often depend on small streams as water sources through the summer (Flenniken et al. 2001, Stanley and Knopf 2002, Evans et al. 2004). Thus, these small streams are of interest to water users across the basin, especially during warm summer months when water demand is high. However, our understanding of climate change impacts on streamflow in the UCRB is mainly limited to a small number of 7^{th} and 8^{th} order (large) rivers (Christensen et al. 2004, Christensen and Lettenmaier 2007). Little is known about how small stream hydrology will be altered under climate change, and the possible impacts on water users and stream-dependent ecosystems.

Riparian areas are of particular concern because they are critical to regional biodiversity despite covering a small percentage of the landscape (Knopf et al. 1988, Sabo et al. 2005). Riparian vegetation provides habitat for birds and other wildlife, provides biomass inputs for instream food webs and often facilitates maintenance of healthy fish populations (Naiman et al. 1993, Machtans et al. 1996). Riparian vegetation also plays a key role in the physical structure of river systems by mitigating the effects of flooding disturbance, stabilizing stream banks, controlling sediment erosion and improving water quality (Brauman et al. 2007, Vincent et al. 2009). Understanding how riparian plant communities will be impacted by climate change will be critical for managing these important riparian and stream-dependent ecosystems (Seavy et al. 2009, Perry et al. *In review*).

In this study, we will focus on climate change impacts on small (1st-3rd order) stream low flows and potential effects on riparian ecosystems. In arid and semi-arid regions of the western US, it is likely that some perennial streams will shift to intermittent flow regimes in response to climate-driven changes in timing and magnitude of precipitation, runoff, and evapotranspiration. Climate-driven changes to key abiotic parameters (e.g. discharge rate, ground water levels) are likely to affect stream ecosystem attributes such as habitat availability, ecosystem productivity, and biological community structure. For example, because melting snow sustains groundwater inputs in the late summer months, earlier runoff due to earlier snowmelt may result in water supply reductions during low flow periods. In addition to impacting water users during an already water-stressed season, changing flow conditions such as intermittent flow and lower alluvial water tables reduce water available for riparian plants (Figure 1).

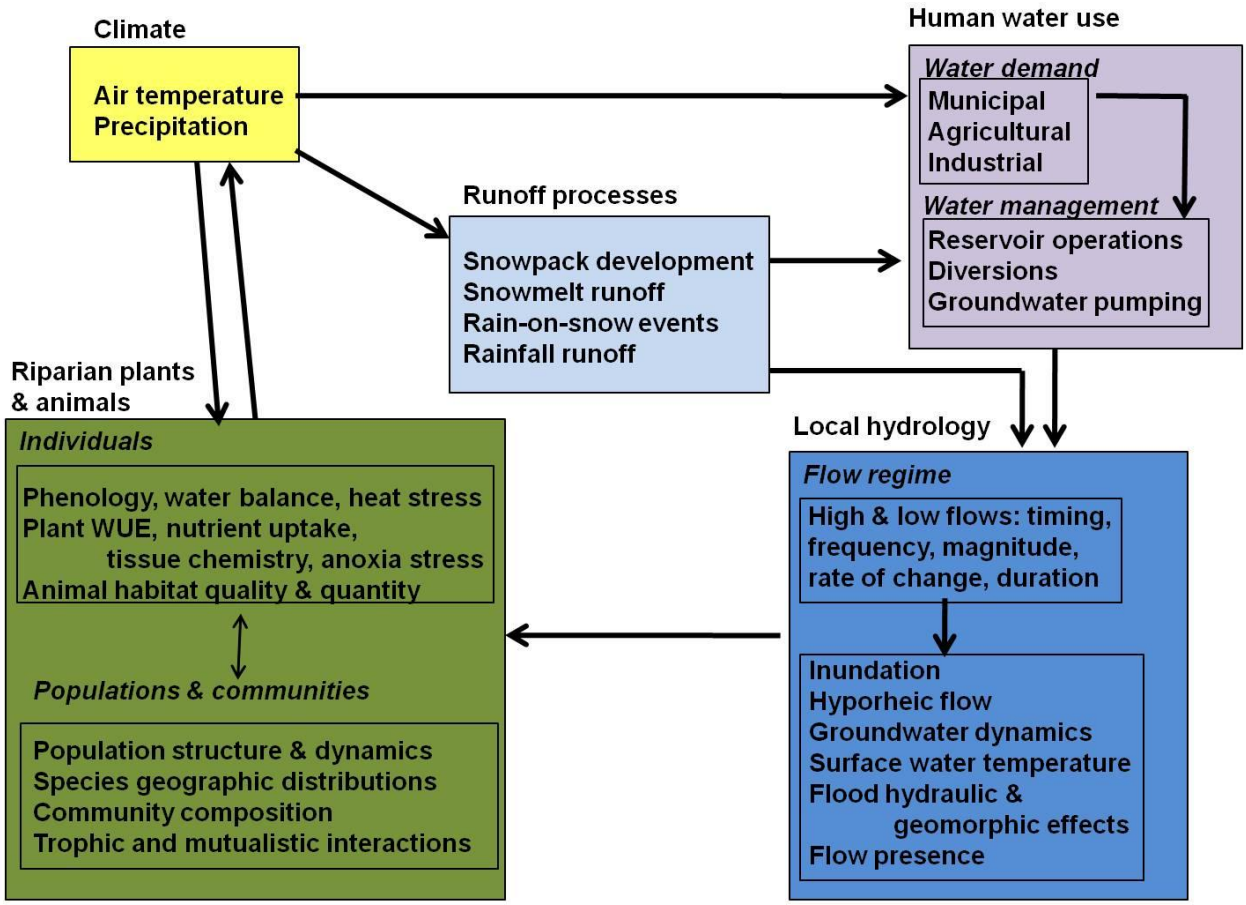

Figure 1. Adapted from Perry et al. *In review*. Linkages between climate, hydrology, human water use, and riparian ecosystems on small streams in the Upper Colorado River Basin.

In the UCRB, we hypothesize that riparian plant composition (including species makeup, life form, life history, native/invasive status, and physiognomic/structural attributes) will change due to drying stream hydrology under future climate change (Bagstad et al. 2006, Stromberg et al. 2010, Perry et al. *In review*). Riparian plant species variation in drought tolerance can cause plant composition to shift along a wet to dry gradient (Stromberg et al. 1996, Stromberg et al. 2005, Shaw and Cooper 2008); in some cases invasive species may be better suited to the drier conditions (Glenn and Nagler 2005, Lite and Stromberg 2005, Merritt et al. 2010). Also, we

expect woody and herbaceous riparian vegetation to respond over different time scales to drying conditions: woody vegetation composition could shift gradually over decades whereas herbaceous riparian vegetation is likely to respond more rapidly to drier conditions. We anticipate that as hydrologic conditions change from wet to dry, there will be shifts in riparian vegetation assemblages, including potentially negative effects on some native species and positive effects on some invasive species (Perry et al. *In review*). For example, increased temperatures and decreased water availability are likely to impact relatively drought-intolerant native cottonwood and willow more than the drought tolerant invasive species tamarisk and Russian olive (Rood et al. 2003, Stromberg et al. 2007, Reynolds and Cooper 2010).

In a recent, related study, we investigated the potential for gaged streams in the UCRB to shift from a perennial to intermittent flow regime under a warmer climate using low-flow metrics derived from historical data (Reynolds and Shafroth *In review*.). We analyzed historic discharge records from streams in the UCRB and found that approximately two-thirds of gaged stream reaches included in our analysis are currently perennial and the rest are intermittent (i.e., they have some zero flow days on record). We showed that there are perennial streams in the UCRB that have low baseflow, low minimum flows and high minimum-flow variability that may lead to increasing streamflow intermittency in the future. This work is currently limited to gaged streams, however, most low-order streams are ungaged.

We propose to undertake two phases of research relevant to the Bureau of Reclamation's Southern Rockies LCC Project Task Areas by examining changes to surface water low flows and resulting changes to riparian ecosystems, including distribution of invasive riparian plants, under future climate changes in the Southern Rockies LCC region. Our research tasks directly address Task Areas A, "projecting future water availability" and B "projecting the resiliency and vulnerability of natural or cultural resources that affect or are affected by water resources management in a changing climate."

Task 1: Modeling low flows on ungaged streams

First, we propose to build on our recently completed stream gage analysis (Reynolds and Shafroth *In review*.) by modeling low flow indexes on ungaged streams across the UCRB and evaluating the potential for streams to increase the number of zero flow days, incur zero flow days where there were none before, and decrease minimum flows under various climate change scenarios. Moline (2007) modeled stream low flow characteristics on the Colorado Plateau using classification and regression tree (CART) analysis. CART modeling has been widely used in the environmental sciences and performs well in tests with other environmental matching models (De'ath and Fabricius 2000, Evangelista et al. 2008, Kampichler et al. 2010). We propose to use CART analysis to build on Moline's (2007) work by extending the study area to the entire UCRB and modeling stream low flows under hypothesized future climate scenarios.

The CART analysis will use physical data as predictor variable inputs to the model. Physical data layers of climate will be derived from PRISM data available online (Parameter-elevation Regression on Independent Slopes Model, http://www.prism.oregonstate.edu/). Data layers on non-climate variables including elevation, geology, and drainage density will be obtained from The Nature Conservancy (TNC). The input variables will be used in CART models to predict baseflow, minimum flows, the number of zero flow days and other low flow metrics on gaged streams. We will then use the results of the CART models to predict low flow metrics on ungaged streams, based on physical characteristics of each ungaged stream reach (Figure 2). We will use estimates of future climate in the UCRB and estimates of streamflow

reductions in the published literature to estimate the impact of climate change scenarios on low-flows (Christensen and Lettenmaier 2007). The results of this modeling analysis will be maps of the UCRB demonstrating how low-flow hydrology across the UCRB might change under a future warmer, drier climate. For various scenarios and thresholds of low-flow change, we will develop GIS layers and maps to estimate low-flow change across ungaged streams in the UCRB. Map products will show 1st-3rd order streams in the UCRB classified by low-flow categories such as future percent change in zero flow days and future percent change in base flow. Low flow categories indicated on the map products will reveal groups of streams whose low-flow hydrology may be more or less vulnerable to future changes in climate.

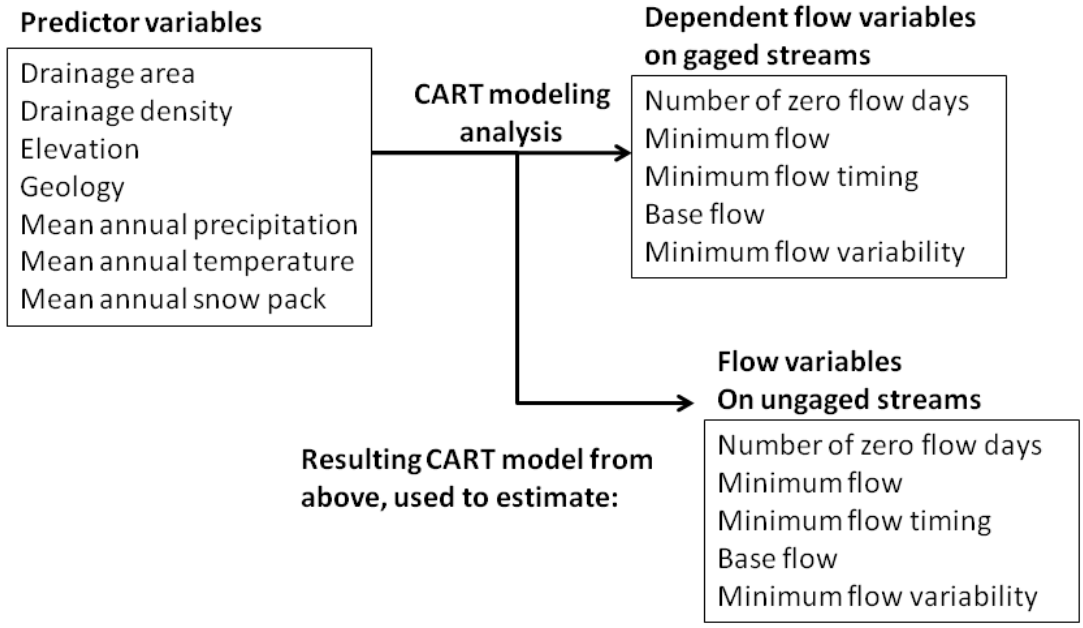

Figure 2. The process of using CART analysis to model low flow metrics on gaged streams followed by implementing the resulting models to predict low flow metrics on ungaged streams.

Task 2: Analyze potential shifts in riparian vegetation: field data collection on a gradient from perennial to intermittent streams

Second, we propose to evaluate the impacts of reduced low-flows on riparian plant communities within five different UCRB sub-regions identified by the developers of the USGS StreamStats program in Colorado and Utah (Kenney et al. 2007, Capesius and Stephens 2009): three above 7500 feet (Uinta, Wind River, and Rocky Mountains) and northern and southern low elevations (divided by an approximate east-west boundary line across the downstream edge of the Green River's desolation canyon and the Gunnison River Basin (Figure 3). Within each sub-region, we will sample along a gradient from perennial to intermittent flow regimes, to allow a space-for-time substitution approach for examining effects of stream drying. This approach is similar to that undertaken by Stromberg et al. (2010) in their assessment of potential effects of climate-change on riparian vegetation along the San Pedro River, AZ.

We will identify sites on gaged and un-gaged streams, based upon our stream gage analyses (Reynolds and Shafroth *In review.*) and the results from Task 1. We will select several stream reaches for sampling along a perennial to intermittent gradient within each subregion. Based on our experience in the region, likely candidate study areas that include both perennial

and intermittent streams will occur in the middle elevation ranges. At the lowest elevations in the basin, most of the streams are intermittent. At the highest elevations, most streams are snowmelt, ground water –fed with perennial hydrology. However, at the lower elevation range of snowmelt ground-water streams are streams that are likely to be significantly impacted by longer, drier summers because they exist with fewer groundwater inputs but higher evaporative demands due to being at a lower elevation.

On each study stream reach, we will measure several abiotic and biotic variables. Data on climate for each study stream reach will be compiled from the PRISM (Parameter-elevation Regression on Independent Slopes Model, http://www.prism.oregonstate.edu/) database of historic, modeled climate data at an 800 m resolution across the US. At each site we will collect data on the geomorphologic and hydrologic characteristics by measuring cross-sectional topography of the stream channel and floodplain and obtaining measurements of stream discharge. Where possible, we will select study streams that have stream gages on them, however to capture representative streams in each region we will also include sites that do not have gage records. On sites without gages, we will visit at least once per month during the growing season and obtain measurements of stream discharge or note the absence of flow. For ungaged stream sites, we will also use the StreamStats modeling program to estimate annual flow metrics (Kenney et al. 2007, Capesius and Stephens 2009). Along each cross-section of the floodplain where we collect topographic data, we will measure canopy cover by the line-intercept method. We will collect data on shrub and herbaceous vegetation by establishing sampling plots (2 m x 5 m) along the flood plain cross section to sample representative plant communities within different geomorphic surfaces on the flood plain (Scott and Reynolds 2007). In each plot we will identify all plant species in the plot and estimate cover for each species. Monitoring across a hydrologic gradient (perennial to intermittent) will provide the opportunity to develop statistical relationships between flow parameters and riparian responses that can be used to help predict riparian vegetation changes under climate change-driven stream drying (Konrad et al. 2008). We will use multivariate analyses to categorize streams by low-flow attributes and by vegetation composition characteristics. The results will be groups of streams by low-flow attributes (e.g., streams with less than 10 zero flow days per year) and corresponding plant community composition (e.g., *Salix* or drought-intolerant species-dominated plant communities). We will then be able to predict how riparian vegetation along streams with decreasing low-flows under climate change may respond to such decrease in water availability (Stromberg et al. 2010).

Products

The results from tasks 1 and 2 will be reported in a final report and a peer- reviewed manuscript to be published upon the completion of the research activities. In addition, we will publish maps of forecast changes in stream flow hydrology and potential changes in riparian vegetation online in an informative and interactive website accessible to water and land managers. Finally, our results will be presented in a meeting to Southern Rockies LCC partners, Reclamation, TNC and other interested partners upon completion of the manuscript and website.

Enhancement of natural resource management in the Southern Rockies LCC

The research in tasks 1and 2 addresses the need for information on climate change impacts on small stream hydrology and ecology and the great amount of stream length that is covered by small streams in the UCRB. There is a tremendous information gap regarding stream-

flow riparian vegetation relationships on small streams in the UCRB and research task 2 will address this knowledge gap. The benefit of this research will be to inform land and water managers, and scientists about the likely impacts of climate change on stream low flows during a critical water supply period (late summer and early fall), and about the likely impacts of climate change on riparian ecosystems and non-native riparian plant invasions. Resulting products will include GIS layers and maps available online in an interactive website that can be used by SRLCC water managers, land managers, scientists, and citizens to inform decision-making and improve understanding of climate change effects on low flows and riparian plant communities along streams in the UCRB.

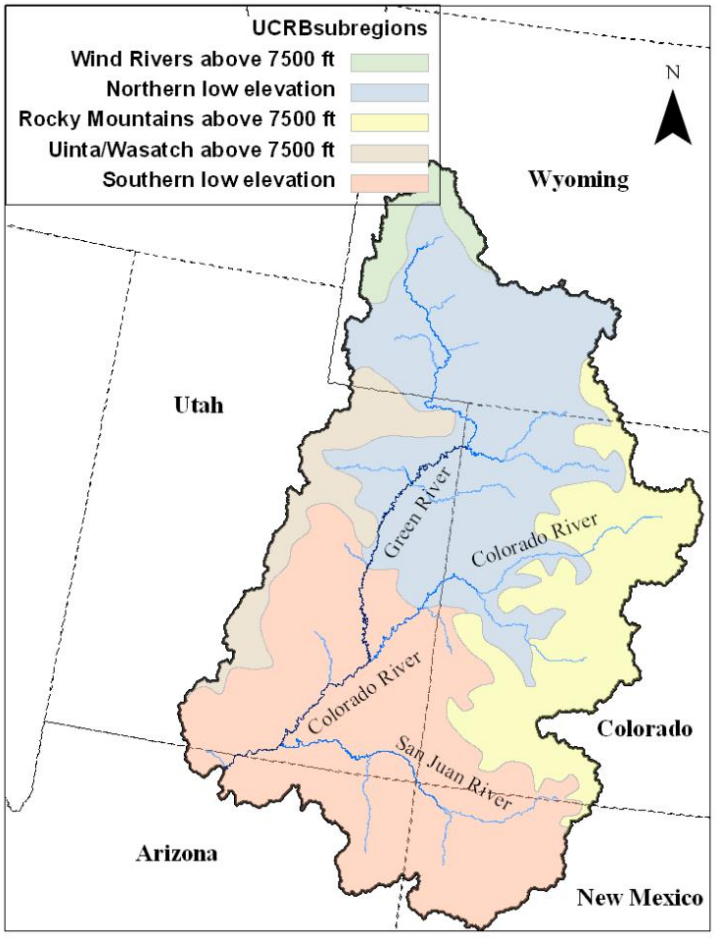

Figure 3. Map of the Upper Colorado River Basin with subregions identified with shading and major rivers (6-8th order) identified in blue.

Sources of Non-Federal Funding

Non-federal support for this research will come from the contribution of lead scientist Poff's time and salary, support from Colorado State University's unrecovered Facilities & Administrative (F&A) costs and from The Nature Conservancy's contribution of scientist John Sanderson's time and salary as well as GIS technical support. See Budget proposal and Budget justification details below pp 18-20.

Project schedule

Research will occur fall of 2011 through winter of 2013. Task 1: Modeling low flows on ungaged streams will occur in fall 2011 and winter/spring 2012 with a report on modeling results completed by September 2012. Study site selection and sampling of UCRB stream sites will occur during spring through early fall of 2012, with data analysis and manuscript writing occurring in fall 2012 and winter 2013. Manuscript submission is anticipated to occur by summer 2013, with a final report, final presentation, and website products complete by September 2013.

Technical Proposal: Project Evaluation Criteria

A. Technical merit

1. Project Scope

- Our proposed research will address the following two primary research question: (1) how will small stream (1^{st}-3^{rd} order) low flow hydrology be impacted by predicted longer, drier summers in the Upper Colorado River Basin under climate change and (2) in turn, what will be the resulting impacts on riparian plant communities? To address these research questions we will undertake two major tasks: (1) modeling stream low flow metrics on ungaged streams in the UCRB and (2) sample riparian plant communities along a hydrologic gradient (perennial to intermittent) to develop statistical relationships between flow parameters and biotic responses that can be used to help predict biotic changes under climate change-driven stream drying (Konrad et al. 2008).

- Research task 1 will address Project Task Area A, "Projecting future water availability and quality." Specifically, we will investigate the impacts of climate change on watershed hydrology by modeling low flow on ungaged streams across the UCRB and by evaluating the potential for minimum flows to decrease or for the number of zero flow days to increase in the future. (See page 5, above, for detailed methods). In addition to the general applicability to Task Area A, our results will relate specifically to Task Area A-b by assessing the strengths and weaknesses of our CART modeling approach relative to other process-based hydrologic modeling approaches to estimating low flows at the watershed scale. Also, we will contribute information relevant to Task Area A-d, as the CART analysis will include geology and valley geomorphology, which can be closely related to groundwater-surface water interactions. Ground water-surface water interactions are likely to be quite important near the threshold between perennial and intermittent streamflow.

- Research task 2 will evaluate the impacts of reduced low-flows on riparian plant communities by sampling across the UCRB along a gradient from perennial to intermittent flow regimes, to permit a space-for-time substitution approach for examining effects of stream drying (see page 5, above, for detailed methods). This second objective addresses Project Task Area B, "Projecting the resiliency and vulnerability of natural or cultural resources that affect or are affected by water resources management in a changing climate," specifically addressing Task Area B-a: projecting changes in the distribution of riparian, wetland, or aquatic communities. Our analysis of riparian plant communities will also address Task Area B-d by providing information to clarify whether

non-native riparian vegetation will increase or decrease under projected climate change scenarios and along a wet to dry stream gradient.

2. *Ability to Accomplish Scope*
   a. Research task funding and team capability

- Task 1 will require Reynolds salary, Poff salary, Shafroth salary and TNC funding to support data compilation, synthesis, GIS processing, CART analysis and final map making based on the CART analysis results. We have allocated 4 months of Reynolds salary, 1 month of Poff salary, and 0.5 months of Shafroth salary to this task. We anticipate the CART analysis and manuscript writing to begin in September 2011 and with a report on modeling results completed by September 2012.

- Task 2 will require Reynolds salary, Poff salary, field technician salary, travel funds, Shafroth salary and TNC support for study site selection, field data collection, data analysis and manuscript writing. We have allocated 10 months of Reynolds salary, 4 months of Poff salary, and 0.5 months of Shafroth salary to Task 2. We anticipate hiring temporary staff: a field crew leader and two field technicians for 4 months during the summer to assist in field data collection. The field crew will need a vehicle and lodging while they are conducting field sampling, so we have allocated 4 months of a rental truck, 48 nights of camping and 12 nights of hotel stays for the 4 month sampling effort. Small equipment such as tape measures, pin flags, and data sheets are already owned by the department and will not need to be purchased. Study site selection and field season preparation will occur during spring 2012. Field data collection will occur May-August 2012 by Reynolds and the field technicians with advisory assistance from Poff, Shafroth, and TNC. Data analysis and manuscript writing will be lead by Reynolds and start in fall 2012 with a manuscript submission anticipated by summer 2013, and completed final presentation and website products by September 2013.

- Our research team is prepared to begin the proposed tasks immediately upon entering into a financial assistance agreement with Reclamation. All the members of our team have accomplished projects similar in scope as the proposed research as both PIs and team members. Co-PI Dr. Poff has been a professor at Colorado State University since 1997 and has an accomplished record of publications and on-going research projects. Poff has published more than 90 peer-reviewed journal articles, reports and book chapters during his career and is well-suited to guide the success of this project. Co-PI Dr. Reynolds is a post doctoral researcher and has published four peer-reviewed articles since completing her dissertation in 2009, has two more in review, and two in preparation. Both Co-PIs show excellent promise to carry out and complete a successful research project. In addition, collaborator Dr. Patrick Shafroth brings 20 years of experience conducting research in a variety of riparian systems in the semiarid western US and more than 30 related publications. Collaborator Dr. John Sanderson brings highly relevant expertise to the project through his role as the Water Program Director and Senior Freshwater Ecologist at The Nature Conservancy, with much of his work focused on the interface between water needs for human activities and ecosystems in the UCRB (See Appendix A: *Curriculm vitae*).

b. Relevance of the project to the Southern Rockies LCC

- The proposed research will be focused on the Upper Colorado River Basin (UCRB) which lies at the center of, and comprises a majority of the Southern Rockies LCC. For feasibility reasons, we are limiting the project spatial extent to one major river basin (UCRB), however due to similarities in physiography, climate, hydrology, and vegetation the results from this work will be applicable to the rest of the Colorado Plateau and neighboring southern Rocky Mountain region.

- Our research will complement existing efforts by Southern Rockies partners such as Reclamation, the Forest Service, The Nature Conservancy, the US Geological Survey and other University researchers. In many cases, the efforts of land management agencies to analyze climate change impacts on river ecosystems are on a large scale, which is the case with Reclamation's Colorado River Basin Study (see more details below in section *d*, page 12).

  The US Forest Service Rocky Mountain Research Station has launched an effort to model streamflow metrics under future climate conditions in six large river basins in the western US (http://www.fs.fed.us/rm/boise/AWAE/projects/modeled_stream_flow_metrics.shtml). This Forest Service effort includes modeling stream flow low-flow metrics on stream segments in the UCRB. However, the model they use was calibrated in the Pacific Northwest and therefore carries an unknown degree of error when extrapolated to different regions such as the UCRB. The results from our work will complement the Forest Service effort to model stream flow on small streams in the UCRB by building a statistical model specific to the UCRB. It will be valuable to compare the results of these two efforts for a more complete understanding of climate change impacts in the Southern Rockies LCC.

  The Nature Conservancy is working in the state of Colorado to develop Watershed Flow Evaluation Tools (WFET) for each of Colorado's nine major river basins (http://conserveonline.org/workspaces/eloha/documents/template-kyle). The goal of developing the WFETs is to help water stakeholders account for non-consumptive water use needs in each basin and plan for future water use management with all appropriate consumptive and non-consumptive water uses in mind. The Colorado River Basin is one of the basins in which the State and TNC are focusing. Again, our research will inform the State's and TNC's efforts to understand long term impacts of climate change on small streams, a smaller scale than is currently accounted for in the WFET modeling efforts. Our data will also provide more detailed information on riparian plant community – stream flow relationships than currently exist for WFETs in Colorado, which mainly focus on one species (the native cottonwood tree).

  In early 2011, the USGS launched its Colorado River Basin study, designed to compliment Reclamation's basin study (see below) and to focus on estimating ET rates via remote sensing, model ground water and ground water use across the basin and assess environmental flows across the basin. Our small-scale, more detailed research and results will inform this large-scale effort.

  In addition, fish biologists at Colorado State University are also investigating the impacts of stream warming and drying on Rocky Mountain native fish. Our results on

stream drying can facilitate assessments of how changes in hydrology will affect a suite of river-dependent biota.

- Our proposed research will build upon projects already undertaken by CSU in collaboration with The Nature Conservancy (TNC) and the US Geological Survey (USGS). Moline (2007), under the advisement of Dr. Poff and TNC scientists, modeled streamflow characteristics on the Colorado Plateau using a CART analysis. More recently, we and collaborators at the USGS (Dr. Patrick Shafroth) analyzed historic discharge records from streams in the UCRB and showed that there are perennial streams in the UCRB that have low baseflow, low minimum flows and high minimum-flow variability that may lead to increasing streamflow intermittency in the future (Reynolds and Shafroth *In review*.). We propose to use CART analysis to build on Moline (2007) and Reynolds and Shafroth's (*In review*.) work by extending the study area to the entire UCRB and by extending the scope of the analysis to include future climate change scenarios. In addition, we will partner with TNC to use data layers of physical attributes (elevation, annual precipitation, temperature, drainage density, and others) developed by TNC for the UCRB to build the models (Sanderson *Pers. comm.*).

- Water and land managers in the Southern Rockies LCC will benefit from this research with increased and more detailed understanding of climate change impacts on stream low flows during a critical water supply period: late summer and early fall. Our research will inform managers of likely impacts on riparian ecosystems and non-native riparian plant invasions. Resulting products will be immediately available to managers at the end of the project in 2013 and will include GIS layers and maps online in an interactive website. The interactive website product will help inform decision-making and support the needs of SRLCC resource managers in understanding the impacts of changing stream flow hydrology and riparian plant communities.

- Our results will be broadly applicable to land managers across the Southern Rockies LCC region, but we have confirmed support from partners at the US Forest Service and the National Park Service in the Colorado Plateau region (see letters of support below).

c. Dissemination of results

Written/technology transfer

In addition to the final written report that will be completed in compliance with the Southern Rockies LCC grant requirements, we anticipate a peer reviewed journal article that describes the findings of the CART analysis and the analysis of riparian vegetation along a perennial-intermittent stream gradient. The CART analysis will result in GIS layers of data on how stream low-flow may change under future climate change scenarios. We will also produce interactive maps based on resultant GIS layers that will be published on an informative website for land and water managers. The website will include maps and information describing our findings with respect to how stream low flows and riparian vegetation may change under future climate scenarios. The goal of the website will be to communicate our results to managers so that our findings may be used in decision making for climate change adaptation. We will coordinate with Reclamation and the Southern Rockies LCC to link our website through their venues.

Presentations

We anticipate making a presentation to Southern Rockies LCC partners, Reclamation, TNC and other interested parties when the final results of this research are finalized in 2013. There are many interested parties based in Boulder and Denver, CO which is where we anticipate hosting a meeting to present our results and discuss the implications with researchers, water and land managers in these organizations.

d. Connection to Reclamation Project Activities

As a university, we do not receive Reclamation water and do not plan to conduct research on Reclamation land or facilities. However, this research effort is centered on the UCRB where there is currently a major effort by Reclamation to analyze water supply and demand under climate change scenarios and projections through the Colorado River Basin Water Supply & Demand Study (the Basin Study, http://www.usbr.gov/lc/region/programs/crbstudy.html). Our research will support and compliment the efforts of the Basin study by providing data on a smaller resolution than is normally possible for the large-scale Basin study.

More broadly, our research will fill information gaps stated in the recent joint report by Reclamation and the Army Corps of Engineers, "Addressing Climate Change in Long-Term Water Resources Planning and Management" (http://www.usbr.gov/climate/userneeds/). Our research will directly address the information gaps that currently exist with respect to the impact of climate change on watershed-scale hydrology and riparian ecosystems. Our work will enhance our currently limited understanding of how low flows will change under future climate and in turn, the impacts on riparian vegetation.

In Reclamation's recent report on climate change and water resources in the western US, "SECURE Water Act Section 9503(c) - Reclamation Climate Change and Water 2011," the focus is on large river hydrology (http://www.usbr.gov/climate/index.html). The model results summarized in this report integrate hydrologic information across large areas for mostly 7^{th} and 8^{th} order rivers. Our research on small stream hydrology and dependent riparian vegetation would supplement Reclamation's large-scale focus by providing information for water users and land managers on a smaller scale across the UCRB.

Finally, our research focus on the impacts of climate change falls under one of Reclamation's Science and Technology Program's three priority research areas: climate change adaptation (http://www.usbr.gov/research/science-and-tech/index.html). The results of our research will be compiled through maps and other interactive features on an informative website to illustrate potential changes to stream low flows and riparian vegetation composition under climate change. Our research will be readily accessible to land and water managers and citizens on the web to support their decision-making with respect to climate change adaptation.

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Westmacott, J. R. and D. H. Burn. 1997. Climate change effects on the hydrologic regime within the Churchill-Nelson River Basin. Journal of Hydrology **202**:263-279.
Zhang, X. B., K. D. Harvey, W. D. Hogg, and T. R. Yuzyk. 2001. Trends in Canadian streamflow. Water Resources Research **37**:987-998.

Environmental and Regulatory Compliance

Our project will not impact the surrounding environment, there will be no earth-disturbing work involved with our project. Due to our minimal time spent at each study site, there will not be any affect on any endangered or threatened species in the project area. We will not be working in areas with wetlands, only riparian habitat and therefore there will be no impact on any wetlands. We will not be working where there are known archeological sites. Our project will not result in any modification to any water delivery system.

Required permits and approvals

Our field sites will be on public lands: Forest Service, Bureau of Land Management or potentially National Park Service land and we will work with the appropriate agencies to obtain necessary permits and approvals.

Funding Plan

Cost-share for the proposed research will be met two ways: through Colorado State University (CSU) and also through partners at The Nature Conservancy (TNC). Dr. LeRoy Poff (Co-PI on this project) will be contributing 5 months of salary over the two year project duration towards the proposed research ($50,985 of salary and fringe, and $24,601 IDC at 48% and 48.5%). In addition, CSU is contributing the difference between the full CSU indirect rate (yr 1 = 48%, yr 2 = 48.5%) and the negotiated Cooperative Ecosystems Study Unit (CESU) indirect rate (17.5%) of the total direct costs towards the proposed research ($27,818). Our collaborator Dr. Patrick Shafroth at the USGS will be supporting this research by offering expertise in riparian ecosystem ecology and contributing two months of his time toward the research ($11,464). Also, our partners at The Nature Conservancy are working on research that is closely aligned and synergistic with our proposed research. Dr. John Sanderson, lead scientist at TNC, has agreed to work with Dr. Lindsay Reynolds (Co-PI on this project) to share TNC GIS data layers from the UCRB for use in the CART modeling analysis. TNC is also keenly interested in the outcome of both the CART modeling effort (Task 1) and the field data collection of riparian communities along a low-flow gradient (Task 2) which will supplement TNC research on understanding streamflow –ecology relationships in the UCRB. Our proposed research would fill a current information gap on small streams regarding flow-ecology relationships. Dr. Sanderson has agreed to support our proposed research with TNC research funds for by cost sharing his salary and associated fringe totaling $15,000.

Table 1. Summary of non-Federal and Federal funding sources.

Funding Sources	Funding Amount
Non-Federal Entities	
1. a) Professor LeRoy Poff, Colorado State University salary and fringe	$50,985
1. b) CSU Indirect on Poff salary	$24,601
2. CSU Indirect difference on total requested Reclamation funding	$27,818
3. Dr. John Sanderson, The Nature Conservancy	$15,000
Non-Federal Subtotal:	**$118,404**
Other Federal Entities	
1. Dr. Patrick Shafroth, US Geological Survey	$11,464
Other Federal Subtotal:	**$11,464**
Requested Reclamation Funding:	**$105,755**
Federal Subtotal:	**$117,219**
Total Project Funding:	**$235,623**

Letters of Commitment

The Nature Conservancy
Protecting nature. Preserving life.™

Cost Sharing Commitment Form

The Nature Conservancy agrees to supply in-kind match in the amount of $15,000, covering the period of the award and including pre-award costs incurred as of August 1, 2010[1], to Colorado State's project entitled "Modeling low streamflows and assessing the ecological impacts of potential stream drying under climate change in the Upper Colorado River Basin" under the direction of Dr. LeRoy Poff. The Nature Conservancy agrees to supply a report of the support to the University as required by the sponsoring agency. The report will include details of the actual expenditures and dates of the in-kind match, broken out by cost categories (e.g. salaries, travel, supplies, etc.)

[1] From the Bureau of Reclamation Southern Rockies LCC Grant Application Instructions: "In no case will pre-award costs incurred prior to July 1, 2010, be considered for cost-share purposes."

By: John Sanderson Date 8/1/2011

Name: John Sanderson, Ph.D. Title: Water Program Director / Senior Freshwater Ecologist

Contributions:

Individual:

Personal time:	
John Sanderson, Water Program Director– 195 hours	$10,484
Jan Koenig, GIS Analyst - 54.5 hours	$ 1,582
Travel	$ 144
Total Direct Costs	**$12,210**
**23% Indirect*	*$ 2,808*
Grand Total	**$15,018**

**please see attached Negotiated Indirect Cost Rate Agreement between The Nature Conservancy and the Department of Interior.*

United States Department of the Interior

U.S. GEOLOGICAL SURVEY
Fort Collins Science Center
2150 Centre Avenue, Building C
Fort Collins, CO 80526

August 3, 2011

To whom it may concern:

This letter is to confirm that one pay period of my salary will be contributed in each of two years to the research and tool development proposed by Drs. Lindsay V. Reynolds and N. LeRoy Poff of Colorado State University (proposal title: "Modeling low streamflows and assessing the ecological impacts of potential stream drying under climate change in the Upper Colorado River Basin."). The total dollar amount of this contribution will be $11464. There are no time constraints on the availability of this salary contribution, but it is anticipated that it will be split between the two years of the proposed project. This is contingent on my continued employment with the U.S. Geological Survey (I am a "permanent" federal employee).

Sincerely,

Patrick Shafroth
Research Ecologist, U.S. Geological Survey
shafrothp@usgs.gov

Letters of project support

Letter from the US Forest Service to follow by mail shortly after the submission of this proposal to grants.gov.

United States Department of the Interior

NATIONAL PARK SERVICE
Southeast Utah Group
Arches and Canyonlands National Parks
Hovenweep and Natural Bridges National Monuments
2282 S. West Resource Boulevard
Moab, Utah 84532-3298

IN REPLY REFER TO:

August 3, 2011

Michelle Maher
U.S. Bureau of Reclamation
WaterSMART Applied Science Grants
Southern Rockies Landscape Conservation Cooperative

Dear Ms. Maher and Project Review Panel,

I write this letter to express support of the National Park Service (NPS) for the proposal "Modeling low streamflows and assessing the ecological impacts of potential stream drying under climate change in the Upper Colorado River Basin" submitted by L. V. Reynolds and N. L. Poff. We believe it is critical to understand the extent to which vulnerable riparian habitats in semiarid regions of western North America may be affected by climate change, especially within watersheds in and near NPS units and other treasured landscapes of the West. Riparian habitats in the western U.S. are under threat from invasive species, fragmentation, alternative energy development, river regulation and climate change. Understanding potential future trajectories for these critical habitats is essential for managing the persistence of native plant communities, wildlife habitat, and water resources. This proposal deals with riparian habitats within a geographic region of great concern to conservation in terms of the potential for degradation and loss of riparian woodlands in semiarid landscapes-all critical to the health of federal, state, and private western landscapes.

The development of models linking climate predictions, stream flows, and the growth responses of riparian plants can provide specific decision support tools for NPS and other land managers. These tools will prove essential in order to effectively manage for the conservation of critical wildlife habitat, native plant communities, and water resources.

Please strongly consider this proposal.

Sincerely,

Kate Cannon
Superintendent
Southeast Utah Group

Table 2. Budget Proposal

Budget Item Description	Computation		Recipient Funding	Reclamation Funding	Total Cost
	$/Unit And Unit	Quantity			
Salaries And Wages					
Reynolds	$3333/mo	14 mos		$46,662	$46,662
Poff	$8125/mo	5 mos	$40,626		$40,626
Field crew leader	$13/hour	640 hrs		$8,320	$8,320
Field technician	$10/hour	640 hrs		$6,400	$6,400
Field technician	$10/hour	640 hrs		$6,400	$6,400
Fringe Benefits					
Full-Time Employees	25.3%	$20,542	$10,359	$11,939	$22,298
Part-Time Employees	15%	$3,168		$3,168	$3,168
Travel					
Lodging for field crew camping and hotels	$2,520			$2,520	$2,520
Rental SUV	$3,750			$3,750	$3,750
Final presentation	$.45/mile	100 miles		$45	$45
Equipment					
Item A					
Supplies/Materials					
Office Supplies					
Construction					
Contractual/Construction					
Item 1					
Environmental And Regulatory Compliance					
Publication page charges				$800	$800
Reporting					
Total Direct Costs			$50,985	$90,004	$140,989
Indirect Costs – 17.5%				$15,751	$15,751
Indirect Costs – 48, 48.5%			$24,601		$24,601
Other Federal					
US Geological Survey			$11,464		$11,464
Other Cost Share					
CSU Unrecovered F&A			$27,818		$27,818
The Nature Conservancy			$15,000		$15,000
Total Project Costs			**$129,868**	**$105,755**	**$235,623**

Budget Narrative

Salaries and Wages

In order to complete tasks 1 and 2, the salaried time of scientists Reynolds and Poff is required. In addition, for the completion of task 2, a crew of field technicians will be needed to complete the field sampling of riparian vegetation along streams in the UCRB. A field crew leader ($13/hour) and two field technicians ($10/hour) will be hired in spring of 2012 and work for 4 months: May-Aug 2012 to complete sampling tasks in the UCRB.

Fringe benefits

The fringe rates for CSU are set at 25.3% for Faculty (Poff) and Post-doctorate researchers (Reynolds) whereas field technicians would qualify as Non-student hourlies at a 15% fringe rate.

Travel

During field sampling in the summer of 2012, field crew technicians will require a vehicle and access to camping and hotel lodging. Renting a truck from the CSU fleet is $450/month plus $0.39/mile. To visit sites across the UCRB, the crew will travel 5,000 miles over four months, which will total $3,750 in vehicle rental charges. In addition, the crew will be camping for 48 days over the 4 months ($15 campsite/night) and hotel stays for 12 nights over the four months ($150/night), for a total of $2,520 in lodging fees.

Publication/page charges

We anticipate one manuscript will be produced and published in a peer reviews journal as a result of this work. Page charges of $50/page result in $800 of page charges for a 16 page paper.

Reporting

Financial, semi-annual and final reports will be written and submitted by Reynolds and Poff. Reynolds and Poff salaries will be required to complete all reporting and this cost has been accounted for in the *Salaries* (see above). Also, we have anticipated some mileage costs to travel to Boulder/Denver, CO to give a final presentation to Reclamation, TNC and Southern Rockies LCC interested parties at the conclusion of the proposed research.

Indirect costs

CSU and the Bureau of Reclamation are members of the Cooperative Ecosystem Studies Unit (CESU), a consortium of Universities and federal agencies that have negotiated indirect rates. If granted by WaterSMART, the funding for the proposed research would be routed through the CESU office to CSU, therefore qualifying for the negotiated CESU 17.5% indirect rate.

Total cost

The total amount requested from WaterSMART Reclamation is $105,754. The total amount to be cost-shared by CSU and The Nature Conservancy is $118,404. USGS will contribute $11,464. The grand total cost of the research is $235,623.

Appendix A. Principal Investigator *Curriculum Vitaes*

N. LeROY POFF

	Phone: 970-491-2079 (office)
Department of Biology	970-491-2414 (lab)
Colorado State University	FAX: 970-491-0649
Fort Collins, CO 70523-1878	E-mail: poff@lamar.colostate.edu

PROFESSIONAL PREPARATION:

Hendrix College	Biology	B.A., 1978
Indiana University, Bloomington	Environmental Science	M.S., 1983
Colorado State University	Biology	Ph.D., 1989
University of Maryland	Ecology	Post-doc, 1990-1992

PROFESSIONAL APPOINTMENTS:

Professor, Colorado State University, July 2007-present
Director, Graduate Degree Program in Ecology, CSU, August 2008-present
Associate Professor, Colorado State University, Dept. Biology, July 2002-2007.
Assistant Professor, Colorado State University, Dept. Biology, July 1997-2002.
Research Scientist, University of Maryland, Dept. Zoology, 1992-1997.
Senior Scientist, Trout Unlimited, Arlington VA, 1996-1997.

PUBLICATIONS (of >90 peer-reviewed articles and book chapters):

5 most relevant to this proposal

Poff NL, MI Pyne, BP Bledsoe, CO Cuhaciyan, DR Carlisle. 2010. Developing linkages between species traits and multiscaled environmental variation to explore vulnerability of stream benthic communities to climate change. ***Journal of the North American Benthological Society*** (in press)

Webb CT, J Hoeting, G Ames, M Pyne, **NL Poff**. 2010. A structured and dynamic framework to advance traits-based theory and prediction in ecology. ***Ecology Letters*** 13:267-283.

Poff NL, JD Olden, NKM Vieira, DS Finn, MP Simmons, BC Kondratieff. 2006. Functional trait niches of North American lotic insects: trait-based ecological applications in light of phylogenetic relationships. ***Journal of the North American Benthological Society*** 25:730-755.

Mims MC, JD Olden, ZR Shattuck, **NL Poff**. 2010. Life history trait diversity of native freshwater fishes in North America. ***Ecology of Freshwater Fish*** 19:390-400.

Poff, NL, JD Allan, M Bain, J Karr, K Prestegaard, B Richter, R Sparks, J Stromberg. 1997. The natural flow regime: a paradigm for river conservation and restoration. ***BioScience*** 47:769-784.

5 other significant

Poff, NL, BD Bledsoe, CO Cuhaciyan. 2006. Hydrologic variation with land use across the contiguous United States: geomorphic and ecological consequences for stream ecosystems. ***Geomorphology*** 79:264-285. [Invited for Binghamton Symposium]

Poff, NL, JD Olden, D Merritt, D Pepin. 2007. Homogenization of regional river dynamics by dams and global biodiversity implications. ***Proc. Natl. Acad. Sci.*** 104:5732-5737.

Poff NL, JD Olden, DS Strayer. (in press) Climate change and freshwater extinction risk. Pages xxx-xxx in *Species Extinctions and Climate Change* (L. Hannah, Ed.), Island Press.

Poff NL 1997. Landscape filters and species traits: towards mechanistic understanding and prediction in stream ecology. ***Journal of the North American Benthological Society***16:391-409.

Lytle, DA, **NL Poff**. 2004. Adaptation to natural flow regimes. ***Trends Ecol. Evol.*** 19:94-100.

SYNERGISTIC ACTIVITIES:

Laureate, College of Natural Sciences, Colorado State University (one of two), 2010-2013.
President, North American Benthological Society (elected), 2006-2007.
Monfort Professor, Colorado State University (one of two university-wide), 2005.
Aldo Leopold Fellow, Ecological Society of America. (One of 20 nationwide in 2004)
Land & Water Australia Visiting Scholar Fellowship, Griffith Uni, Brisbane QLD, 2005.
ISI *Highly Cited Researcher* (http://hcr3.isiknowledge.com/home.cgi)
Editorial Board, *Freshwater Biology*, 1996-present.
Associate Editor, *Limnology & Oceanography*, 1999-2000.
Faculty Participant, NSF IGERT: Program for Interdisciplinary Mathematics, Ecology, and Statistics, Colorado State University (2003-2008)
Co-PI and faculty participant, NSF IGERT: Integrated Water Atmosphere and Ecosystem Education and Research, Colorado State University (2011-2016)
Member, NRC Committee on USGS Water Resources Research, 2001-2006.
Plenary Presentations: Keynote, 5th Biennial Symposium, Freshwater Mollusk Conservation Society (Little Rock, AR, 2007); International Symposium on "Restoration of Spanish Rivers" (Madrid, Spain, 2006); 4th Conference of the International Society for Ecological Informatics (ISEI, Busan, Korea, 2004), 5th International Symposium on Ecohydraulics (Madrid, Spain, 2004); 9th International Symposium on River Research & Applications (Albury NSW, Australia, 2003); "Floods in a changing climate," (sponsored by Royal Society of London, 2001)

GRADUATE AND POSTDOCTORAL ADVISORS

Graduate Advisor: J.V. Ward, Colorado State University / EAWAG, Switzerland (retired)
Post Doctoral Advisor: J.D. Allan, University of Michigan

THESIS ADVISOR AND POSTGRADUATE-SCHOLAR SPONSOR (last 5 years)

Postgraduate-Scholar Sponsor/Mentor

Dr. Kevin McCluney (CSU), Dr. Lindsay Reynolds (CSU); Dr. Laura Perry (CSU); Dr. Julie Zimmerman (now The Nature Conservancy); Dr. Nicole Vieira (now CO Division of Wildlife)

Graduate Advisor

Dr. Julian Olden (Asst. Prof. U. Washington); Dr. Debra Finn (post-doc Oregon State U.); Dr. Angie Moline (North. Ariz. U.); Julia McCarthy (US EPA Denver); Christine Albano (Grand Canyon Trust, Flagstaff AZ); Daniel Auerbach (PhD student), Matthew Pyne (PhD student), Thomas Wilding (PhD student), Ryan McShane (PhD student)

Number of graduate students (graduated/current) since 1997: M.S. (4/0), PhD (4/4)
Number of post-docs supported (and visiting scholars in lab) since 1997: 6 (5)
Number of undergraduates supported in lab since 1997: 22

CURRENT GRANTS

"Dimensions: Collaborative Research: An integrative traits-based approach to predicting variation in vulnerability of tropical and temperate stream biodiversity to climate change." US National Science Foundation. $1,357,218. 04/01/11 – 03/31/16

"Predicting relative risk of invasion by saltcedar and mud snails in river networks under different scenarios of climate change and dam operations in the western United States." US Environmental Protection Agency – STAR. $599,745. 07/01/08 – 06/30/11

"Impact of climate change and variability on nation's water quality and ecosystem states." US Environmental Protection Agency – STAR. $129,999. 10/1/10 – 9/30/13

"Native & Invasive Wetland & Riparian Plant Species in the Western United States." US Geological Survey. $230,518. 7/1/2008 – 6/30/2011

"Colorado basin watershed flow evaluation tool." Camp Dresser McKee. $21,407. 01/01/10 – 08/31/10

"IGERT: WATER - Integrated Water Atmosphere and Ecosystem Education and Research." US National Science Foundation. $2,728,060. 2010-2015

LINDSAY V. REYNOLDS

Department of Biology
Colorado State University
Fort Collins, CO 70523-1878

Phone: 970-226-9174 (office)
970-420-1411 (cell)
FAX: 970-491-0649
E-mail: Lindsay.reynolds@lamar.colostate.edu

EDUCATION

Ph.D. Colorado State University, 2009
B.A. Environmental and Evolutionary Biology, Dartmouth College, 2003

PROFESSIONAL EXPERIENCE

Postdoctoral research (2009-current) *Colorado State University Department of Biology, Fort Collins, CO* Advisor: Dr. N. LeRoy Poff (CSU) and Dr. Patrick Shafroth (USGS)

Research associate (2010): *Effects of large dam removal on Elwah River riparian forests, Washington*, funded by US Geological Survey and the National Park Service

Dissertation research (2004-2009): *Causes and management of exotic riparian plant invasion in Canyon de Chelly National Monument, Arizona*, Graduate Degree Program in Ecology, Colorado State University. Advisor: Dr. David Cooper (Colorado State University)

Research associate (2008): *Southeastern Alaska Wetland Characterization*, funded by US Cold Regions Research and Engineering Laboratory (CRREL). Principal Investigators: Dr. David Cooper (Colorado State University), David D'Amore (US Forest Service), and Robert Lichvar (CRREL)

Research associate (2006): *Characterization of fen condition, and restoration plan development in the San Juan Mountain, Colorado*. Funded by Environmental Protection Agency Region VIII. Principal Investigators: Dr. David Cooper (Colorado State University) and Dr. Rod Chimner (Michigan State University)

Field Biologist (Spring-Summer 2004): *Northern Goshawk Off-highway vehicle Study*, Plumas National Forest, California, Redwood Sciences Laboratory. Principal Investigator: Jeffrey Dunk, Humbolt State University

Field Biologist (Winter 2004): *Wyoming Wolf Recovery Program*, Gros Ventre Bioregion and Grand Teton National Park. Principal Investigator: Mike Jimenez, US Fish and Wildlife Service

PUBLICATIONS

Reynolds, L. V. and P. B. Shafroth. *In review*. Potential shifts in minimum flow stream hydrology in the Upper Colorado River Basin under climate change: a stream gage analysis.

Perry, L. G., D. A. Andersen, **L. V. Reynolds**, S. M. Nelson, P. B. Shafroth. *In review*. Vulnerability of riparian ecosystems to elevated CO2 and climate change in arid and semiarid western North America. Global Change Biology.

Reynolds, L. V. and D. J. Cooper. 2011. Ecosystem response to removal of exotic riparian shrubs and a transition to upland vegetation. Plant Ecology **212** (8):1243-1261.

Jarnevich, C. S. and **L. V. Reynolds.** 2011. Challenges of predicting the potential distribution of a slow-spreading invader: a habitat suitability map for an invasive riparian tree. Biological Invasions **13** (1): 153-163.

Reynolds, L. V. and D. J. Cooper. 2010. Environmental tolerance of an invasive riparian tree and its potential for continued spread in the Southwestern US. Journal of Vegetation Science **21** (4): 733-743.

Reynolds, L. V. and D. J. Cooper. 2010. Causes, management and the future of exotic riparian plant invasion in Canyon de Chelly National Monument, Arizona, *in* Melis, T.S., Hamill, J.F., Coggins, L.G., Jr., Grams, P.E., Kennedy, T.A., Kubly, D.M., and Ralston, B.E., eds., Proceedings of the Colorado River Basin Science and Resource Management Symposium, November 18–20, 2008, Scottsdale, Arizona: U.S. Geological Survey Scientific Investigations Report 2010–5135, p. 297-305. http://pubs.usgs.gov/sir/2010/5135/

Reynolds, L. V., M. P. Ayres, T. G. Siccama, and R. T. Holmes. 2007. Climatic effects on caterpillar fluctuations in northern hardwood forests. Canadian Journal of Forest Research. **37** (2): 481-491.

GRANTS AND AWARDS

USGS Climate Effects Network research grant. *Potential effects of perennial to intermittent stream flow regimes shifts under climate change on stream-dependent communities in the Upper Colorado River Basin*. July 2010, $15,000.

Second place, Oral presentations. Front Range Student Ecology Symposium, Fort Collins, Colorado. February 24-25, 2009. $100.

Strategic Environmental Research and Development Program Student Travel Award to the 2008 Ecological Society of America Meeting. Presentation title: *Causes and timing of tamarisk and Russian olive invasion into a southwestern floodplain.* August 2008, $500

Center for Invasive Plant Management, Seed Money Grant Awardee. Title: *Does one invasion lead to another?* May 2007, $4,000

NSF Pre-Doctoral Fellowship Honorable Mention, 2005, 2006

Program for Interdisciplinary Math, Ecology and Statistics (PRIMES) at CSU *Fellowship recipient*, September 2004- December 2005, $40,000

High Honors from the Dartmouth Biology Department, 2003

Willard W. Eggleston Botany Prize (Dartmouth), 2003

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EDUCATION

Ph.D., Plant Biology, Arizona State University, 1999.
M.S., Forest Sciences, Colorado State University, 1993.
B.A., Environmental Studies and Geography. University of California, Santa Barbara, 1989.

WORK EXPERIENCE

Nov 2002-Present	Research Ecologist, USGS-FORT
April 1991-Nov 2002	Various positions at FORT (USGS, NBS, USFWS)
June 1988 – April 1991	Various Research and Teaching Assistantships, U. of California, The Nature Conservancy, U. of Montana, and Colo. State U.

ACADEMIC AFFILIATIONS

Faculty, Colorado State University, Graduate Degree Program in Ecology, and Affiliate Faculty, Colorado State University, Department of Forest, Rangeland, and Watershed Stewardship

RESEARCH EMPHASES

For the past 20 years, Shafroth and colleagues (principle collaborators include J.M. Friedman, G.T. Auble, M.L. Scott, and J.C. Stromberg) have focused their research on understanding relationships between surface and ground-water hydrology, fluvial processes, and the dynamics of native and alien riparian vegetation. This work has often been conducted in the applied context of riparian ecosystem restoration and has a current emphasis on understanding responses of riparian vegetation to integrated effects of climate change and water management.

RELEVANT PUBLICATIONS (17 of 30 peer-reviewed publications)

Stromberg, J.C., P.B. Shafroth and A.F. Hazelton. 2011. Legacies of flood reduction on a dryland river. River Research and Applications. In Press. DOI: 10.1002/rra.1449 Published online 15 September 2010. (http://onlinelibrary.wiley.com/journal/10.1002/(ISSN)1535-1467/earlyview)

Beauchamp, V.B. and P.B. Shafroth. 2011. Floristic composition, beta diversity and nestedness of reference sites for restoration of xeroriparian areas in semi-arid western USA. Ecological Applications 21:465-476.

Andersen, D.C., P.B. Shafroth, C.M. Pritekel, D.A. Lytle, and M.W. O'Neill. 2011. Managed flood effects on beaver pond habitat in a desert riverine ecosystem, Bill Williams River, Arizona USA. Wetlands 31:195-206.

Shafroth, P.B., C.A. Brown, and D.M. Merritt, editors, Saltcedar and Russian olive control demonstration act science assessment. U.S. Geological Survey Scientific Investigations Report 2009-5247. U.S. Department of the Interior, U.S. Geological Survey, Reston, VA. 143 p.

Andersen, D.C. and P.B. Shafroth. 2010. Beaver dams, ecological thresholds, and controlled floods as a management tool in a desert riverine ecosystem, Bill Williams River, Arizona. Ecohydrology 3:325-338.

Shafroth, P.B., A.C. Wilcox, D.A. Lytle, J.T. Hickey, D.C. Andersen, V.B. Beauchamp, A. Hautzinger, L.E. McMullen, and A. Warner. 2010. Ecosystem effects of environmental flows: modeling and experimental floods in a dryland river. Freshwater Biology 55:68-85.

Beauchamp, V.B., C. Walz, and P.B. Shafroth. 2009. Salinity tolerance and mycorrhizal responsiveness of native xeroriparian plants in semi-arid western USA. Applied Soil Ecology 43:175-184.

Scott, M.L., P.L. Nagler, E.P. Glenn, C. Valdes-Casillas, J.A. Erker, E.W. Reynolds, P.B. Shafroth, E. Gomez-Limon, and C.L. Jones. 2009. Assessing the extent and diversity of riparian ecosystems in Sonora, Mexico. Biodiversity and Conservation 18:247-269.

Shafroth, P.B., V.B. Beauchamp, M.K. Briggs, K. Lair, M.L. Scott, and A.A. Sher. 2008. Planning riparian restoration in the context of *Tamarix* control in western North America. Restoration Ecology 16:97-112.

Stromberg, J.C., S.J. Lite, R. Marler, C. Paradzick, P.B. Shafroth, D. Shorrock, J. White, and M. White. 2007. Altered streamflow regimes and invasive plant species: the *Tamarix* case. Global Ecology and Biogeography 16:381-393.

Friedman, J.M., G.T. Auble, P.B. Shafroth, M.L. Scott, M.F. Merigliano, M.D. Freehling and E.R.Griffin. 2005. Dominance of non-native riparian trees in western USA. Biological Invasions 7:747-751.

Shafroth, P.B., J.R. Cleverly, T.L. Dudley, J. Stuart, J.P. Taylor, C. van Riper, and E.P. Weeks. 2005. Control of *Tamarix* in the western U.S.: implications for water salvage, wildlife use, and riparian restoration. Environmental Management 35:231-246.

Shafroth, P.B., J.C. Stromberg, and D.T. Patten. 2002. Riparian vegetation response to altered disturbance and stress regimes. Ecological Applications 12:107-123.

Shafroth, P.B., J.C. Stromberg, and D.T. Patten. 2000. Woody riparian vegetation response to different alluvial water table regimes. Western North American Naturalist 60:66-76.

Springer, A.E., J.M. Wright, P.B. Shafroth, J.C. Stromberg, and D.T. Patten. 1999. Coupling groundwater and riparian vegetation models to assess effects of reservoir releases. Water Resources Research 35:3621-3630.

Scott, M.L., P.B. Shafroth, and G.T. Auble. 1999. Responses of riparian cottonwoods to alluvial water table declines. Environmental Management 23:347-358.

Shafroth, P.B., G.T. Auble, J.C. Stromberg, and D.T. Patten. 1998. Establishment of woody riparian vegetation in relation to annual patterns of streamflow, Bill Williams River, Arizona. Wetlands 18:577-590.

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EDUCATION

Ph.D. in Ecology, 2006
Graduate Degree Program in Ecology, Colorado State University, Fort Collins, CO 80521
Dissertation: Hydrology and conservation of intermountain wetlands

Master of Science in Botany/Field Naturalist Program, 1994
University of Vermont, Burlington, VT 05405

Bachelor of Science in Aeronautical and Astronautical Engineering, 1986
Purdue University, West Lafayette, IN 47907

WORK EXPERIENCE

Co-Direction, Center for Conservation Science and Strategy
The Nature Conservancy of Colorado, Boulder, CO 80302 Oct 2010 – Present

Lead the science program for The Nature Conservancy of Colorado. Ensure program coordination and effectiveness to achieve maximum leverage and on-the-ground conservation outcomes. Represent science to Board of Trustees, major donors, and partners. Supervise five employees and manage six additional staff with responsibilities for wetland, stream, and river outcomes.

Water Program Director / Senior Freshwater Ecologist
The Nature Conservancy of Colorado, Boulder, CO 80302 June 2009 – Present

Lead the water program for The Nature Conservancy of Colorado, including science, policy, development, outreach, and protection components. Manage and allocate $1.7M/yr budget. Participate in statewide and regional water planning for conservation outcomes, including coordination and collaboration with multiple water users and agencies (Colorado Water Conservation Board, Inter-Basin Compact Committee Basin Roundtables, Colorado Division of Wildlife, National Park Service,

Bureau of Land Management, Cities of Fort Collins and Greeley, Denver Water, and others). Synthesize, interpret and apply research and conservation plans to execute on-the-ground conservation and management actions including instream flow and land protection. Serve on graduate committees.

PUBLICATIONS

Kray, J.A., D.J. Cooper, and J.S. Sanderson. Groundwater use by native plants in response to changes in precipitation in a high desert closed basin. Submitted to Journal of Arid Environments.

Dauwalter, D.C., J.S. Sanderson, J.E. Williams, and J.R. Sedell. Identification and implementation of Native Fish Conservation Areas in the Upper Colorado River Basin. In Press at Fisheries.

Sanderson, J. S., N. Rowan, B. P. Bledsoe, N. L. Poff, and W. J. Miller. , N. L. Poff, J. S. Sanderson and T. K. Wilding Watershed Flow Evaluation Tool: Regional environmental flow assessment in Colorado. In Press at River Research and Applications.

Rathburn, S. L., D. M. Merritt, E. E. Wohl, J. S. Sanderson, and H. A. L. Knight. 2009. Characterizing environmental flows for maintenance of river ecosystems: North Fork Cache La Poudre River, Colorado, in James, L.A., S.L. Rathburn, and G.R. Whittecar, eds., Management and Restoration of Fluvial Systems with Broad Historical Changes and Human Impacts, Geological Society of America Special Paper 451, p. 143-157, doi:10.1130/2009.2451(10)

Sanderson, J. S., N. B. Kotliar, and D. Steingraeber. 2008. Opposing environmental gradients govern vegetation zonation in an intermountain playa. Wetlands 28: 1060-1070.

Sanderson, J. S., N. B. Kotliar, D. A. Steingraeber and C. Browne. 2008. The simulated natural hydrologic regime of an intermountain playa conservation site. Wetlands 23:363–377.

Sanderson, J. S. and D. J. Cooper. 2008. Ground water evapotranspiration from wetlands of an arid intermountain basin. Journal of Hydrology 351:344-359.

Sanderson, J. S. 2009. Quantifying non-consumptive needs in Colorado: the Watershed Flow Evaluation Tool. Colorado Water 26:2-4.